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ABSTRACT

Future space operations which can potentially contribute to the accomplishment of space mission goals are discussed. These goals include, (1) support of space observatories, laboratories, and earth applications; (2) manned and unmanned planetary exploration; and (3) exploration and exploitation of the moon. Space operations (or activities) are categorized as launch, transportation, assembly, maintenance, communication, information management, quarantine, and test and demonstration. The focus of the discussion is on space operations which become either feasible, simpler, or less costly because of the presence of manned space bases and availability of low cost transportation systems (LCT). It is noted that:

1. Two classes of LCT are desirable for future space operations; namely (a) an earth to earth orbit logistics system with an earth return capability; and (b) an in-space logistics system capable of major ΔV maneuvers for cislunar space missions.

   The former class of LCT, when used in conjunction with an orbital launch facility perhaps as simple as an unmanned fuel storage depot, can support lower cost lunar and planetary as well as earth orbit missions. The latter class of LCT is potentially capable of lunar ferry use, rescue operations, and unmanned satellite service operations.

2. The existence of manned space bases to and from which LCT systems operate can make feasible, simplify, or reduce the cost of space operations in the areas of assembly, maintenance, test and demonstration, information management, and communications.

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PREFACE

The following Technical Memorandum was written in preparation for and support of a study, conducted by the Scientific and Technical Advisory Committee (STAC), of NASA's Office of Manned Space Flight on "The Uses of Manned Space Flight, 1975-1985". This study was held December 6-9, 1968, at La Jolla, California. The ideas and content of the memorandum have been discussed during its writing with certain members of STAC, but the responsibility for the statements made, however, rests with the present authors.

BELLCOMM, INC.

SUBJECT: Future Space Operations - Case 105-1

DATE: January 28, 1969

FROM: H. B. Bosch
D. Macchia
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TECHNICAL MEMORANDUM

I. INTRODUCTION

Space operations are activities which contribute to the accomplishment of space mission goals. These mission goals include

- support of space observatories, laboratories and earth applications,
- manned and unmanned planetary exploration, and
- exploration and exploitation of the moon.

Inherently space operations are not ends or goals in themselves.

Table I is a general list of space operations which may be conducted on earth or in space; manned or unmanned. The particular mode of implementation (manned or unmanned, earth or in space) will be decided by considerations of convenience, safety, economics, and performance advantage. At present, most space operations are usually carried out from earth or, in some instances, by unmanned in-space facilities. Several operations, particularly in quarantine and maintenance, are currently not done at all. However, current operations and the location from which they are carried out may change with changing space hardware capabilities and space mission requirements. Projected future space operations must be based on future space capabilities and requirements, and current constraints and assumptions must necessarily be re-examined.

Availability of low cost transportation and manned space bases will permit completely new, less costly, or improved space operations. Ultimately the design, development,

TABLE I

ACTIVITIES	DESCRIPTIVE OPERATIONS	EXAMPLES OF APPLICATION
Launch	• Assemble components • Orient vehicle into launch position • Fuel • Checkout (countdown) • Repair	• Near-earth shuttle (orbit-to orbit or orbit-to-earth) • Lunar shuttle • Planetary probes
Transportation	• Retrieve • Reposition • Rescue (escape) • Visit and inspect • Shuttle	• Malfunctioning satellites and other hardware • Personnel • Cargo
Assembly	• Position and connect components • Align and calibrate • Checkout	• Astronomical instrument • Large, complex spacecraft and structures
Maintenance	• Refurbish • Refuel • Checkout • Visit and inspect • Repair	• Communication satellites • Reconnaissance satellites • Astronomical instruments • Logistics and shuttle vehicles
Communication	• Data transmission • Data relay • Tracking • Command and control	• Planetary spacecraft • Earth orbital (communications satellites, reconnaissance satellites, etc.)
Information Management	• Data acquisition (point and operate sensors) • Programming and scheduling • Data screening and selecting • Data storing (recording)	• Planetary spacecraft • Astronomical instruments • Earth sensors
Quarantine	• Isolate • Inspect and test • Discard or Destroy	• Planetary and lunar samples (biota) • Personnel • Radioactive matter
Test and Demonstration	• Set up test • Monitor test • Retrieve test unit	• Earth sensors • Lunar and planetary probes • Critical spacecraft subsystems • Space manufacturing processes

testing, and management of space missions and hardware may be revolutionized. The potential has not been fully appreciated.

Previous space station study has generally concentrated on orbital laboratories and earth applications goals. Possible support of other mission goals was not explored. Because of this, the concept of space operations has generally been rather narrow. Only the obvious assembly, maintenance, communications, and information management operations which are necessary for the accomplishment of a limited set of space station objectives were identified and studied. Possible future space operations have received little attention. In view of this, the following discussion extends beyond what has already been identified and it is partly speculative. The focus of the discussion is on space operations which may be uniquely or better done because of the presence of space bases and the availability of low cost transportation systems.

II. DISCUSSION OF SPACE OPERATIONS

A. Launch

The possible existence of a reusable, low cost transportation (LCT) system for earth-to-earth orbit trips in the 1980's requires a re-evaluation of the current mode of conducting launch operations. Such a system may permit significant reductions in the transportation costs of planetary and lunar missions (Ref. 1). This possibility has not been fully explored to date.

In the extreme, LCT used in association with an orbital launch facility (OLF) can potentially eliminate the vast array of launch vehicles currently in use for manned and unmanned missions. The OLF acts as staging point (i.e., accumulates payload components and fuel) to efficiently utilize the LCT payload capability. A staging point permits ground launch of LCT to occur at more convenient times---periods of good weather conditions, for example---and the ability to store propellant and stages in orbit also allows more leisurely launch rates which take the burden off ground facilities. (These ground operations become expensive if they must be accomplished on a compressed time scale.) An OLF can also divide a transportation job into more easily accomplished legs. For example, a reusable earth-moon shuttle would not have to be designed for earth atmospheric entry, hence it could be a much simpler system than a reusable system designed to go directly from earth to moon and back.

An OLF used to fuel a reusable lunar ferry system is a useful example. Fig. 1 shows a single stage H_2/O_2 shuttle which transports a lunar landing and return system between earth orbit and lunar orbit. Fig. 2 indicates the quantity of propellant which must be supplied to the ferry. A small number of LCT launches could supply this propellant. With LCT at $10/lb it is apparent that the transportation cost for one ferry mission would be two orders of magnitude less than a comparable Apollo mission. Launch of this ferry vehicle directly from earth would require a Saturn V class vehicle (or in-orbit rendezvous of smaller launch vehicle payloads) and the economic advantage of reuse would be much more difficult to achieve.

Previous study (Ref. 2) has not established an absolute technical requirement for an OLF. Furthermore, due to orbit plane problems, desirability of a permanent facility is uncertain. Launch operations of component assembly, vehicle positioning, fuel loading, checkout, and repair if necessary can all be performed in alternate ways. The necessary assembly and checkout operations could be conducted from the mission's manned spacecraft; propulsion modules could be launched from earth and repair tasks could be carried out from the mission spacecraft or a separate logistics launch from earth. Regarding checkout, it is further noted that the current trend is away from large supporting facilities (either on ground or in orbit) and to onboard checkout systems. Advances in computer design will make light onboard computers practical.

An OLF could enhance the probability of mission success for launch operations spanning several months. There may also be possible advantage to assembly and checkout by a non-mission crew. But these considerations are not sufficient to justify its construction. These tentative technical conclusions do not, however, preclude the possible desirability of an OLF as a part of low cost lunar and planetary transportation.

A study of an OLF must include the technical feasibility of supporting many different missions (which an OLF must do if it is to be economically justified). The required degree of OLF complexity must also be determined. An OLF may be solely an unmanned fuel depot or it can increase in complexity with addition of repair and checkout capability. LCT enables one to also consider temporary manning of an OLF during some mission launches. In short there are many possibilities and options, and a study of the economies of an LCT/OLF mode of operation is warranted.

B. Transportation

Transportation operations will be necessary for support of future space stations and hardware. For example, in the assembly of large structures the components need to be positioned and aligned before the proper connections can be made. Repair of a damaged satellite requires either transporting men and equipment to the satellite or returning the satellite to a repair area. A lunar base or earth orbiting station will require the transfer of men and materiel. These transportation operations can be accomplished with orbit-to-orbit shuttle vehicles (e.g., a lunar ferry), unmanned maneuvering stages, or an earth based low cost transportation system.

The possibilities of inter-orbital servicing and ferrying will be discussed in Section D. Shuttle vehicles such as the lunar ferry (Fig. 1) or an unmanned maneuvering propulsion system (Fig. 3) are capable of major propulsive maneuvers and can allow retrieval and repair operations. The lunar ascent/descent stage of Figure 1 (which operates between lunar orbit and the lunar surface) is intended to deliver 10,000 pounds of cargo and return 2,000 pounds, in addition to a three-man compartment. Its performance with different delivery and return loads, which is indicated in Figure 4, shows that this vehicle can be used for a variety of missions other than its intended lunar landing. For example, if a 5,000 pound satellite has ceased working, there are four ways in which its service can be restored using the lunar stage for transportation:

i. The satellite can be repaired on location. Thus, carrying crew but no cargo, the stage is capable of providing 9,140 fps each way on a roundtrip without refueling.

ii. The satellite can be replaced. Here, the stage is capable of 8,210 fps each way, delivering 5,000 pounds and returning empty.

iii. The satellite can be repaired at a space station, this mode requiring two roundtrips. The stage can accomplish this double roundtrip for any mission requiring no more than 7,660 fps each way.

iv. The malfunctioning satellite can be exchanged for a new satellite. Thus, delivering a 5,000 pound satellite and returning with an identical one, the stage can provide 7,020 fps each way.

To relate this capability to potential applications we consider three space stations as described in Table II. The characteristic velocities required to reach some typical satellites from these three space stations are listed in Table III. The significant point is that, inasmuch as these examples are representative of future satellites, a comparison of Table III with Figure 4 shows that all these repair and replacement missions are well within the performance capability of vehicles such as the lunar ascent/descent stage.

Thus, a lunar ferry or a smaller system specifically designed for satellite maintenance can perform the important transportation functions leading to satellite reuse. These operations are practical and potentially lead to significant reductions in the cost of unmanned earth orbital satellite programs as noted in the section on maintenance. This concept of "orbital basing" has been discussed in Ref. 3.

The potential magnitude of manned orbital activities requires an initiation of planning for emergencies. Means and modes of rescue and escape should be available for future near-earth missions. Whether it is coming to the aid of a stranded astronaut whose mobility unit has failed, or enabling the entire crew to leave a severely damaged spacecraft, rescue and escape calls for a variety of transportation modes. In a 1967 Congressional survey (Ref. 4) NASA, USAF, and a number of aerospace firms stated that escape and rescue capability will be a direct by-product of the existence of an earth to earth orbit logistics ferry transportation system. The lunar ferry can also serve this purpose. As an example, transferring from a 30° inclination, 200 n.mi. orbit (station #1) to an equatorial synchronous orbit (station #3) requires $\Delta V = 13{,}910$ fps. This is beyond the capability of the lunar ascent/descent stage (see Fig. 4). However, if the ascent/descent stage is defueled and placed atop the shuttle stage (Fig. 1) then this

Table II. Orbital Description of Selected Space Stations.

SPACE STATION NUMBER	ORBIT ALTITUDE (n. mi.)	ORBIT INCLIN.
1	200	30°
2	200	90°
3	19,323	0°

Table III. Velocity Requirements for Reaching Certain Satellites from Selected Space Stations.

TYPICAL SATELLITE	ORBIT ALTITUDE (n. mi.)	ORBIT INCLIN.	REACHED FROM STATION NUMBER (see Table II)	ΔV* (ft/sec)
Reconnaissance	100	90°	2	360
Physics & Astronomy				
OSO	300	33°	1	1,560
OAO	420	35°	1	2,440
OWL	350	80°	2	4,360
Applications				
ATS	6,000	28°	1	8,290
"	"	"	3	7,550
GEOS	600	80°	2	4,440
Communications				
Syncom	19,323	33°	3	5,730

*Velocity required for a near-optimal combination of an initial plane change, a Hohmann transfer, and a final plane change. Phasing not considered.

combination is capable of going to an equatorial synchronous orbit and returning with an additional 10,000 pound discretionary payload. Therefore, with some adaptation, an existing earth orbit to moon ferry can also provide near-earth rescue and escape capability.

C. Assembly

An in-space capability to assemble, calibrate, and checkout space systems can have a profound effect on the design of these systems. Novel, higher performance, or less complex space hardware for manned and unmanned missions will undoubtedly be feasible. In-orbit assembly can relax many structural, thermal, and configuration design requirements which result from ground launch of a completely assembled check-out system.

Large structures are subject to severe packaging and deployment constraints which limit consideration of such structures. These constraints are major development problems. Assembly capability is, for example, of particular consequence for future development of astronomical telescopes and antennas which are representative of large complex space structures. Benefit would be derived from in-orbit assembly, alignment, and calibration. Assembly operations for large structures in general are suggested by the following examples of astronomical facility requirements (Ref. 5):

Stellar Telescope - Large diffraction limited mirrors (i.e., 1 to 3 meters) could be packaged in separate containers for protection against the launch environment, and integrated with the telescope in orbit.

Solar Telescopes - Focal lengths of up to 75 meters are desirable for large aperture solar instruments. Optimally the optics should be unfolded, because of light scattering, low reflectivity in the ultraviolet wavelengths, and thermal design problems. Ground launch is not practical, hence the telescopes must be assembled from segments to the required length.

X-ray and Gamma-ray Arrays - Large area detectors on the order of 100 square meters for survey and occultation measurements are being considered. These structures could be assembled in conveniently sized segments.

<u>Radio Astronomy</u> - In the infrared wavelength range combinations of large aperture size (100 feet) and high surface accuracy ($\sim 5\mu$) will ultimately be required to achieve diffraction limited performance. Most likely, the aperture will be composed of actively controlled surface elements which will be required to maintain deflections within tolerable limits. In-orbit assembly and alignment is necessary to meet these stringent requirements.

Communications antennas on the order of tens to hundreds of feet in diameter may be required. Design of such antennas for automated deployment will be complex and surface accuracy is poor compared to antennas that could be launched in one piece directly from earth. This is illustrated in Table IV which shows estimated surface accuracies for several candidate antenna structures (Ref. 6). Bell Telephone Laboratories note that the one piece antenna class gives highest gain for a fixed diameter system. These antennas are limited in diameter to the launch vehicle envelope (i.e., less than 33 ft. for a two stage Saturn V). However, a manual assembly and adjustment capability could make "one piece" designs feasible in much larger dimensions.

Orbital assembly operations could also have significant impact on design of orbital satellites and planetary probes. Subassemblies sensitive to the earth launch environment could be packaged in a protective shroud and integrated with the probe in the more suitable space environment. Extended booms, antennas, solar panels, and other appendages would be attached manually, doing away with complex deployment mechanisms. Separate payloads with similar orbit and operational requirements could be mounted on reusable palettes which provide common power, guidance and control, and station keeping services.

An example of a proposed interplanetary probe is shown in Figure 5 (Ref. 7). A large parabolic antenna is required to meet high gain communication requirements at interplanetary distances. This antenna also serves as a solar collector for a solar cell power system. Surface accuracy is to be maintained within a root-mean-square deviation of 0.13 inch over 110 feet. Practical volume limitations during the boost phases dictate that the probe be compactly packaged. Unfurlable structural members and skin of aluminized mylar are therefore used (Fig. 6). The deployment sequence is shown in Figure 6. This procedure is inherently complex, and reliability of performance (due to the fabrication

TABLE IV

ANTENNA TYPE	β	m	ε	Comments
Solid One Piece	.002	3/2	1.2	Diameter Limited by Launch Vehicle Envelope
Rigid One Piece	.004	3/2	2.4	
Petaline	.12	1	10.2	Deployable Antennas
Expandable Truss	.06	1	5.1	
Inflatable	.6	1	51.0	

Where $\varepsilon = \beta D^m$ is rms surface tolerance in mm

$D = 85$ ft is antenna diameter

β and m are parameters as listed

constrained antenna design) over the long transit lifetime (several years) is questionable. Manned assembly prior to final low thrust injection could greatly ease deployment constraints or, more significantly, alter the basic design by enabling the antenna to be installed in the fully deployed configuration.

In summary, an in-space assembly capability can be of significant value in earth viewing, observatory, or planetary probe applications. Continued study of required hardware and assembly techniques is necessary. At this point such hardware requirements are uncertain. It appears likely that space assembly operations will be most efficiently performed by manned maneuvering systems with some form of manipulator mechanism (Refs. 4, 8, 9). Figures 7 and 8 illustrate some possible systems.

D. Maintenance

The performance of regularly scheduled servicing or occasional repair work permits the continued usage of space equipment. Significant economies will result if this can be done in ways which are inexpensive compared to replacing hardware by new launches from earth.

A permanent orbiting station can serve not only as crew quarters and as an operations base, but also as a store for tool kits, special repair equipment (Figures 7 and 8), and a carefully inventoried supply of replacement parts and components. Repairing a sensor onboard a reconnaissance satellite or replacing a component of an orbiting telescope can save a large investment by insuring the continued functioning of sophisticated equipment. For example, the 1966 OAO satellite and mission were lost because of a failure of the system to switch from one of three batteries to another. The first time the automatic switching device failed, the satellite was in view of a ground station. The device was commanded from the ground to disengage itself from the battery. The next time the device locked, however, the satellite was out of range and by the time it reappeared in view of the ground station the power supply had failed completely. It was then impossible to communicate with the satellite. Figure 9 (Ref. 10) shows the equipment stowage in eight bays between the outer octagonal skin and the inner cylindrical structure (which contains the optic train). The panels are attached mechanically with slotted head screws. With some design change in the equipment support, access by man for repair would be feasible. In view of the fact that replacement of the OAO would cost around 50 million dollars, space maintenance becomes an attractive activity.

The refurbishment of earth orbit to lunar surface shuttle vehicles or the refueling of the attitude control systems of unmanned satellites are examples of operations which permit the reuse of space hardware. Satellites which are nearly coplanar with an orbiting space station could be serviced from such a base or they could be returned to the base for repair. If major orbital propulsion capability is available (for example a lunar ferry or orbital shuttle) more distant satellites could also be serviced, as was discussed in Section IIB.

Orbital maintenance can be used to correct malfunctions, in delicate instruments or other payloads, which may be induced by the severe environment of ascent from earth into orbit. The design, manufacture, and testing of much equipment may also be simplified by planning on checkout at the space station, thus relaxing the requirement for exceedingly high reliability and reducing the need for redundancy.

In summary, the capability for orbital maintenance enhances the general conduct of space missions; and the presence of an orbiting (manned) space station is one way of providing this capability. It is also possible that, with sufficiently low cost earth to earth orbit transportation, space maintenance can be conducted directly from earth launch. The economics of these alternative maintenance modes remain to be explored. In any event space maintenance operations are feasible and worthy of consideration for the 1980's.

E. Communication

Space based communication facilities can complement ground based facilities by providing

- relay links for point to point ground communications
- independent viewing platforms for long based interferometry and triangulation measurements, and
- a platform above the atmosphere for operation in the spectrum interfered with by cloud cover, haze and other anomalies.

Operations currently performed by in-space communications systems are data relay and transmission. These are soon to be extended to tracking, and command and control functions.

As communication systems become more complex and costly, manned attendance will be desirable to provide servicing for continued usefulness of large investments. Conversely, with manned attendance, it is practical to utilize large, more sophisticated instruments. It is natural, therefore, to presume that a communications facility associated with a large space station would, by dint of size and complexity, have performance advantages over independent communication system facilities. For example, a large radio dish, perhaps several hundred of feet in diameter, may be practical for deep space tracking and communications operations in conjunction with ground based systems to establish large collecting areas with large baseline separations. A 40 inch aperture optical communications instrument, approaching large astronomical telescopes in accuracy and complexity, might also be utilized. These instruments could, for example, significantly enhance performance of planetary probes by reducing probe power requirements or, alternately, accommodating substantially increased bit rates for a fixed probe power supply. It is not clear, however, that such instruments could, in spite of performance advantages, significantly enhance communication operations compared to smaller independent facilities. Other factors, such as the number of dishes and size of separation baseline, may govern. Smaller, unmanned satellites might then be more practical in achieving desired performance goals.

Tracking and telemetry transmission at planetary distances appear to present the most demanding requirements on communication operations. Precise tracking of planetary probes is of value in performing braking and entry maneuvers, and achieving correct passage distances on planetary encounters for multiple planet flybys. Here tracking accuracy would be improved by triangulation from separate space based and ground based ranging measurements. Moreover, synchronous orbit tracking would be almost continuous because of reduced occultation constraints. If major improvement in tracking accuracy can be achieved it is possible that improved mission mode selection or increased probability of mission success will result (for example, aerobraking unmanned probes for insertion in Martian orbit, or closer approach distance). Study of this possibility is warranted.

Optical communications offer high data rates at low power levels and, consequently, may be well suited for interplanetary manned spacecraft communications. Furthermore, large spacecraft might be visually tracked at planetary distances. Even EVA missions might be tracked on the lunar surface via simple hand held reflectors or beacons. A drawback of ground based optical communications is the interference from cloud cover and other atmospheric anomalies at desired operational frequencies. Space based optical communications would eliminate such constraints. However, it is contended by some schools that microwave communications are adequate for these missions and, in view of operational simplicity, are strongly preferred.

In general it has not been shown that a manned facility is necessary for conduct of communication operations, nor have unique communications operations performed in association with a manned space station been determined. If a large, manned or man attended space station, existing for other reasons, were made available, benefit could be derived from performance advantages resulting from increased instrument size and complexity. This can be assessed only upon more detailed study.

F. Information Management

The use of a space station as a center for collecting information from nearby data generating satellites does not offer any clear advantage over conducting such activities from earth via unmanned data relay satellites. A space station could, however, serve an important function as a central pickup point for films and tapes which have been collected from satellites. (Alternately this purpose could be accomplished directly from earth via manned shuttle vehicles or unmanned orbit to earth data capsules.) Another possible use of a space station is screening or selecting data from unmanned satellites or probes for transmission to earth. This may be a very uneconomical use of astronaut time and is probably better done on earth. For example, it has been estimated that a trained observer takes 5 to 30 minutes to review a single picture from the lunar orbiter spacecraft. Similarly the scheduling of experiments and instrument activities onboard a satellite (other than the manned space station itself) should be programmed from earth rather than from a manned space station.

In summary, the advantages of a nearby space station appear to be (1) an ability to communicate with and direct unmanned satellites when they are beyond the line of sight to ground bases or unmanned communications relay satellites, and (2) to act as a central pickup base for "hard" data such as tapes or film.

G. Quarantine

Quarantine in space may be required for

- isolation and/or growth of viable organisms (i.e., pathological, germ free strains, unique species, etc.)
- isolation of planetary samples
- isolation of crews returning from planetary landing missions.

The use of a space station as an outpost for isolation and/or growth of viable organic forms must be considered extremely speculative at this time. Perhaps experiments or processes requiring quarantine may develop if facilities can be made available for such operations. This application of a space station should be studied further as one possible task of an earth orbital biology laboratory.

Return of samples of the Martian surface and the Venusian atmosphere (or atmospheres of the major planets) has been given serious consideration in NASA advanced mission studies. If sample retrieval is accomplished by unmanned probes there may not be any sure means of remotely testing for life-forms that could be potentially lethal to earth organisms. However, if a sample were returned to earth orbit by propulsive braking, and tested there, the danger of earth surface contamination would be greatly reduced. A facility onboard a space station could allow sophisticated analysis and test prior to transport to the surface.

The same problem exists for manned planetary landing missions. In this case, both planetary samples and men could be quarantined in earth orbit. Long term tests would then be performed on the crew to gain assurance against their contamination by extraterrestrial organisms. This may be required regardless of results from precursor sample return missions. It is conceivable that organisms which could not survive the long return trip (i.e., in a dormant sample container) could survive in a living organism such as man.

In summary, quarantine operations must be rated as speculative now, but conceivably important long term applications can arise. A space station facility may offer a useful, if not a unique, means of solving difficult quarantine problems.

H. Test and Demonstration

Low cost transportation and the existence of a large space base makes manned in-space testing of complete spacecraft or subsystems an attractive possibility. The presence of man during the progress of a test can be of considerable value. A man can intervene to repeat certain measurements or to correct data in the test equipment which might otherwise have forced termination of the test, resulting in loss of data. He can also make adjustments to a test unit and continue with a more meaningful test. But most important, the existence of a low cost logistics system can permit the return (to earth) of the unit under test.

Although preliminary ground tests are necessary, eventual testing in orbit is desirable because the actual operating environment cannot always be simulated successfully on earth. Moreover, orbital testing subjects the unit or system to all elements of the environment simultaneously. For example, orbital testing becomes particularly significant for electrical propulsion systems because of their complexity and long operating time (Ref. 11). In short, orbital qualification of space hardware (lunar and planetary probes, subsystem, earth sensors, etc.) can potentially give more meaningful results.

A decision to test in orbit rather than on earth is solely a question of economics. The potential transportation costs to and from earth orbit in the 1980's may well make orbital testing a planned space operation. In-space testing is not done as extensively as it might be today because it is prohibitively expensive and the design of the in-space test is a major development problem in itself. However, a space base which is already there for other reasons can be used very advantageously for this purpose.

III. SUMMARY AND CONCLUDING REMARKS

1. Low cost, space transportation systems can stimulate development of unique or less costly space operations. Two classes of low cost transportation (LCT) are germane; namely

a. an earth to earth orbit logistics system with an earth return capability, and

b. an in-space logistics system capable of major ΔV maneuvers for cislunar space missions.

Both systems must be capable of transporting crew and varied payloads, and would most likely be reusable.

2. An orbital launch facility, perhaps as simple as an unmanned fuel storage depot, when used in conjunction with a low cost earth to earth orbit logistics system may significantly reduce the cost of lunar and planetary missions. The extent of these economies, the launch facility characteristics, and the launch operations employed are totally undefined at present. A study effort is warranted.

3. A reusable in-space logistics system is potentially capable of several important space transportation operations. These operations include

   a. maintenance, repair, retrieval, and launch of unmanned earth satellites,

   b. use as the ascent/descent stage of an earth orbit-lunar surface ferry, and

   c. rescue operations in cislunar space.

4. The existence of manned bases (e.g., space stations) to and from which LCT systems operate can make feasible, simplify, or reduce the cost of space operations in the areas of assembly, maintenance, test and demonstration, information management, quarantine, and communications. However, a manned base is not essential for most operations since they can alternately be conducted directly from earth with LCT or by unmanned systems. But it is possible that conducting the sum total of potential space operation activities from manned space

bases may be more economical and convenient than the multitude of ways in which such operations would have to be conducted individually.

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Attachment
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Figures

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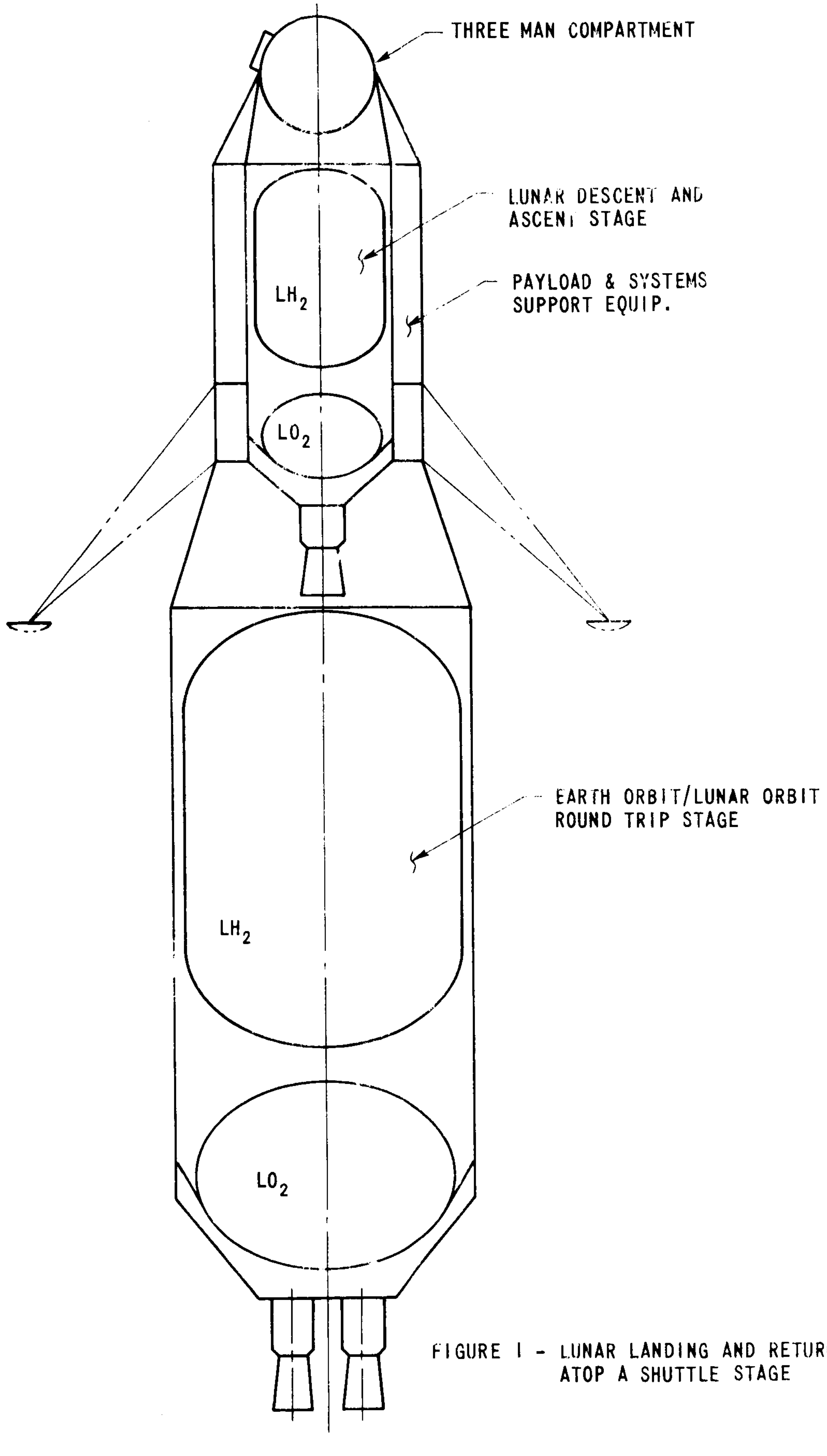

FIGURE 1 - LUNAR LANDING AND RETURN SYSTEM ATOP A SHUTTLE STAGE

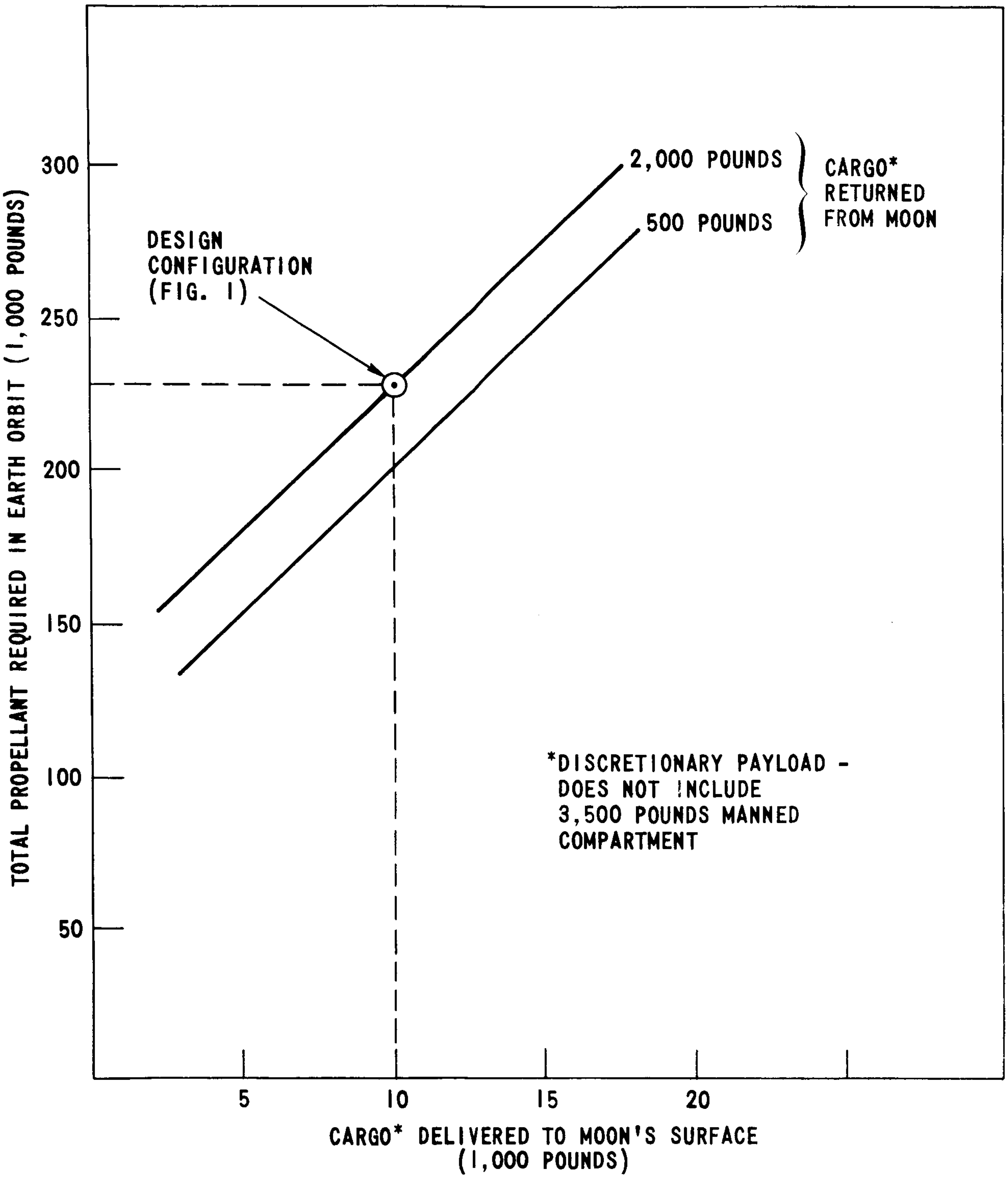

FIGURE 2 - TOTAL PROPELLANT REQUIRED IN 300 NM EARTH ORBIT PER MISSION WITH LUNAR SHUTTLE (FIG. 1)

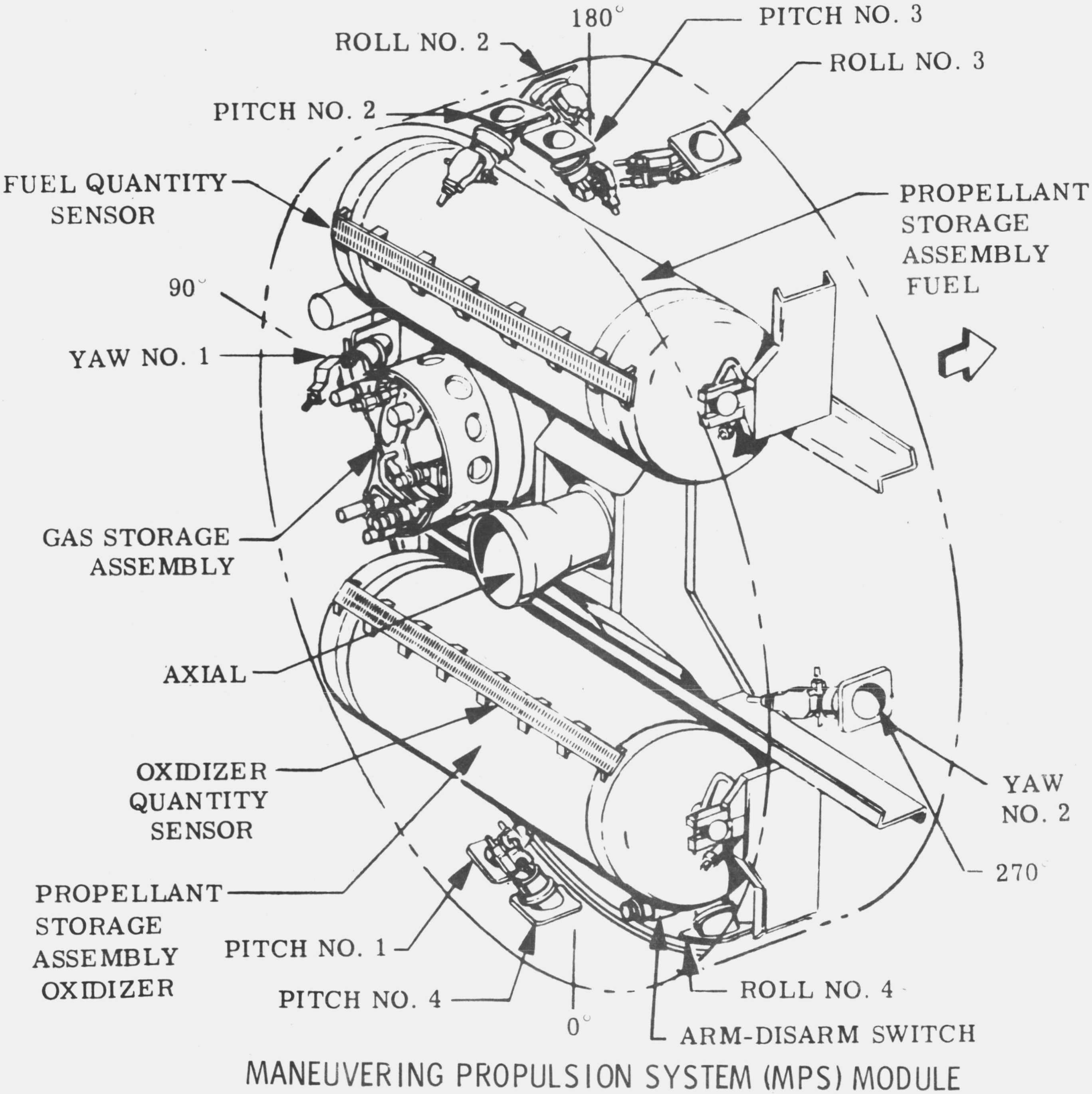

Figure 3. Bell Aerosystems
Maneuvering Propulsion System (from Ref. 3)

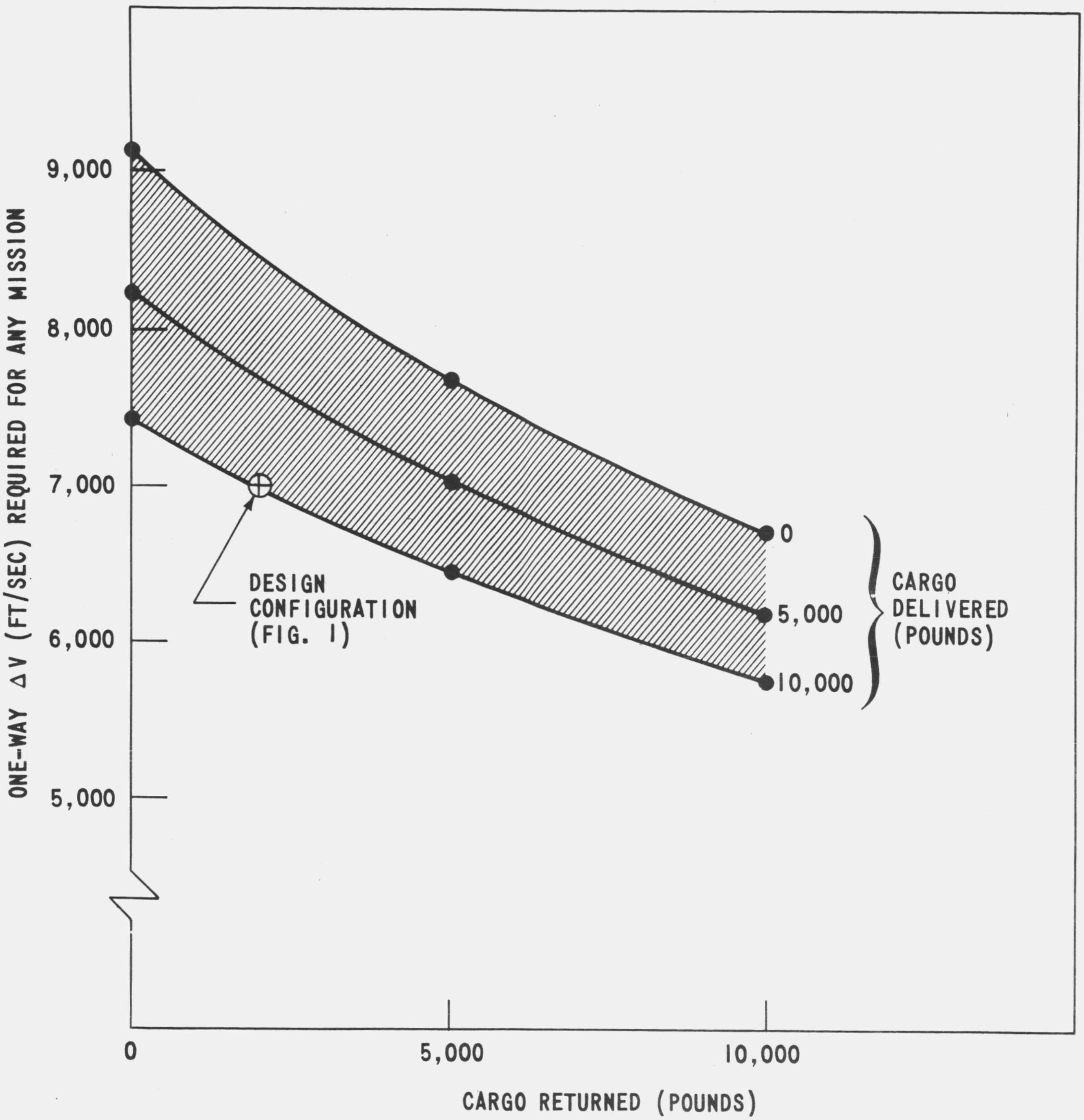

FIGURE 4 - ROUND TRIP MISSION PERFORMANCE CAPABILITY
OF LUNAR ASCENT/DESCENT STAGE

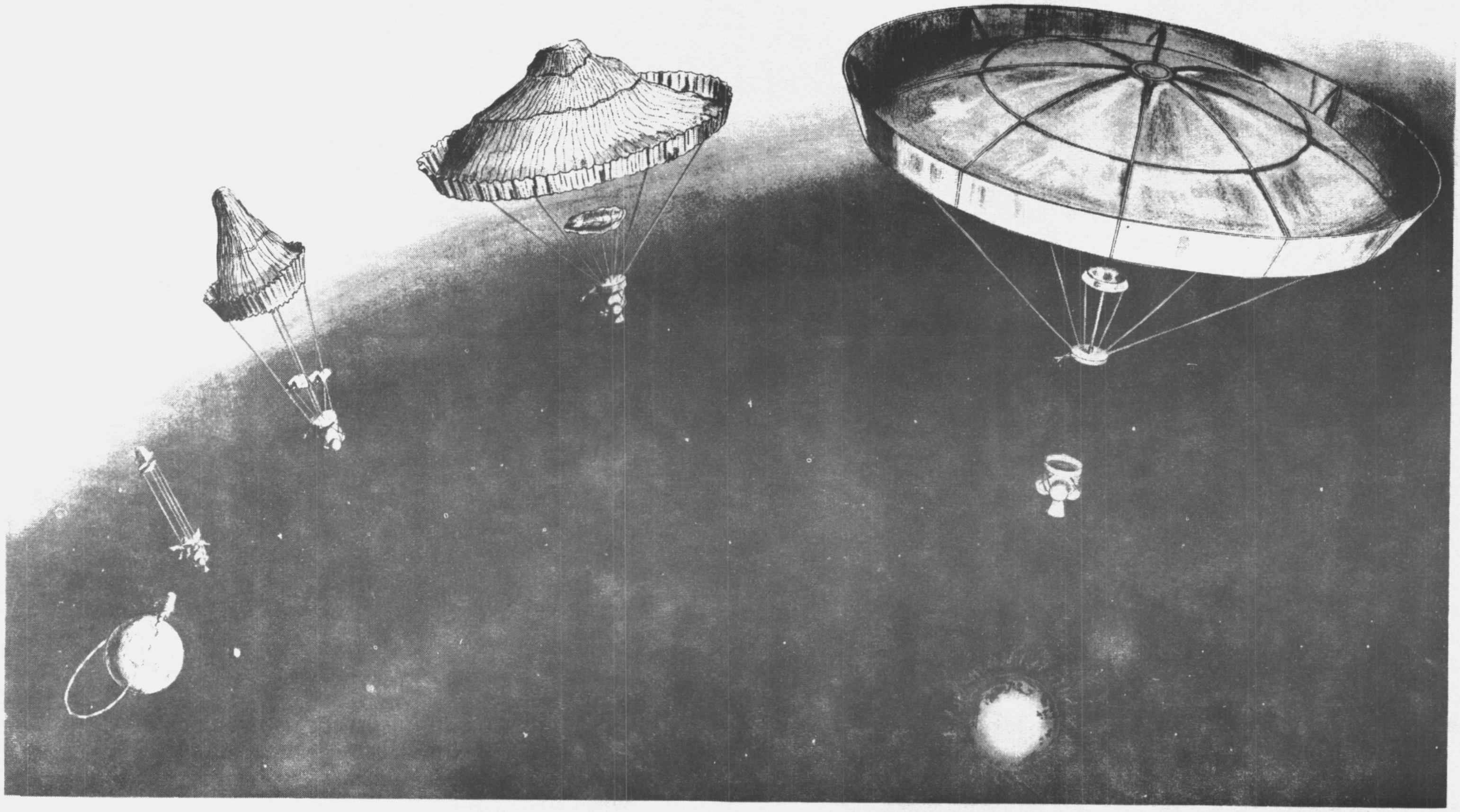

Figure 5. Unfurlable Communications Antenna (from Ref. 7)

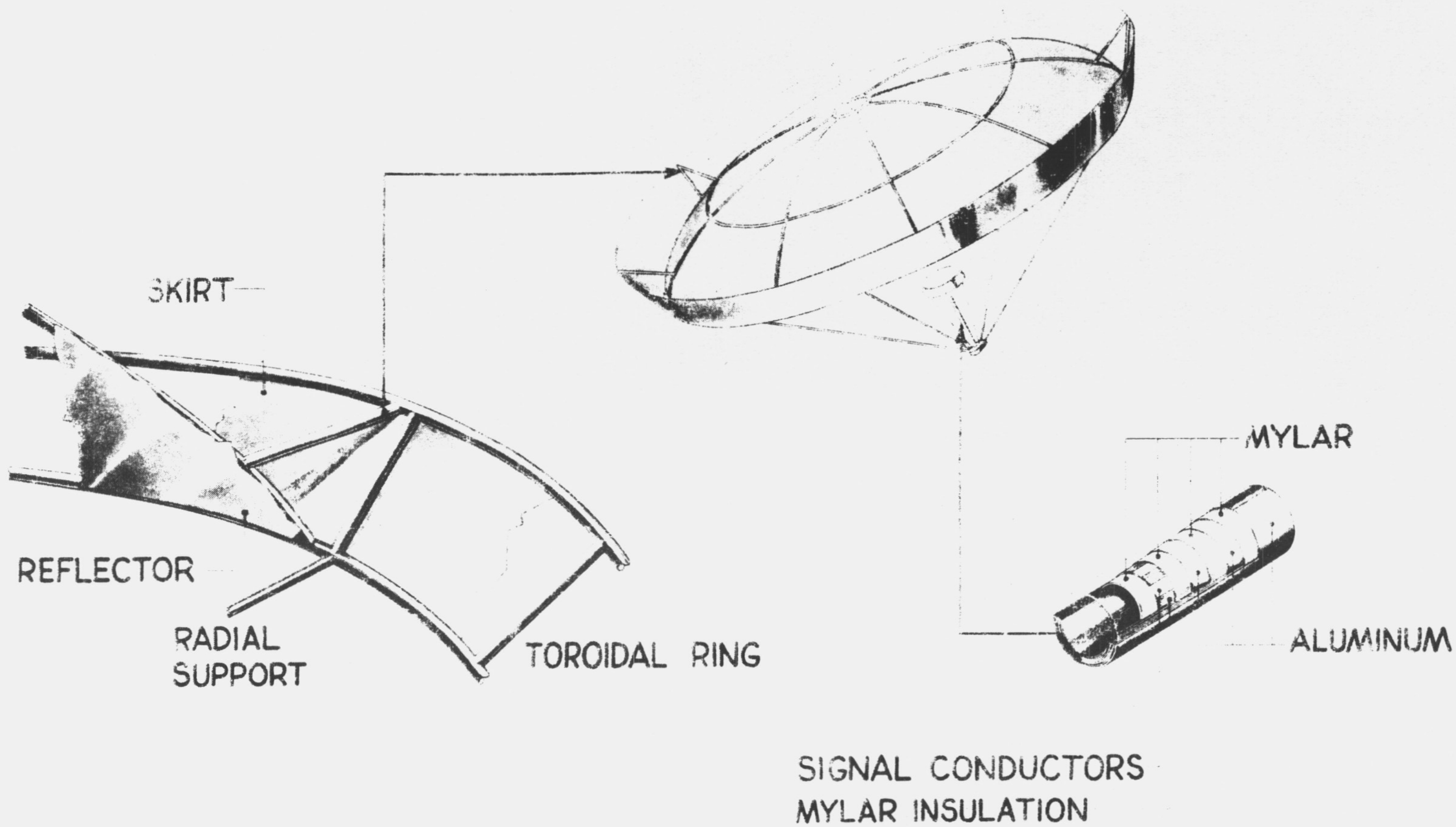

Figure 6. Unfurlable Antenna Structural Details (from Ref. 7)

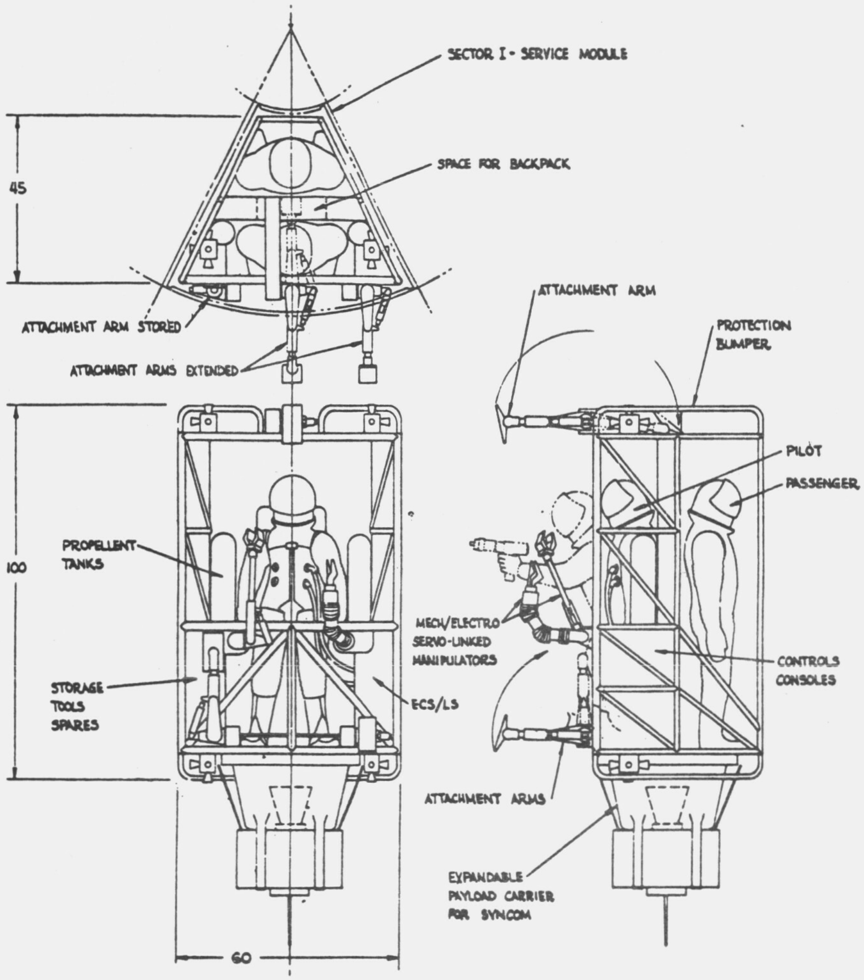

Figure 7. Fairchild Hiller Concept of a Rescue and Work Platform (from Ref. 4)

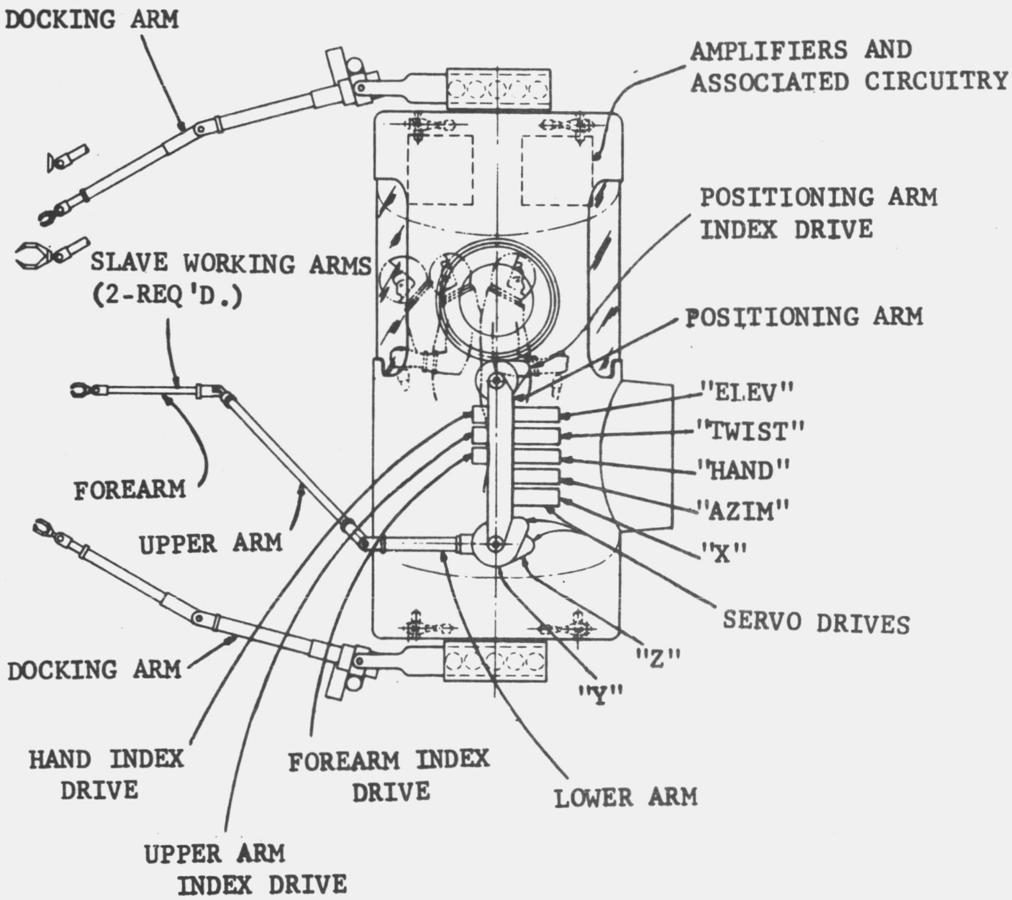

Figure 8. The MSFC-ANL Space Taxi
Electric Master-Slave Manipulator
(from Ref. 8.)

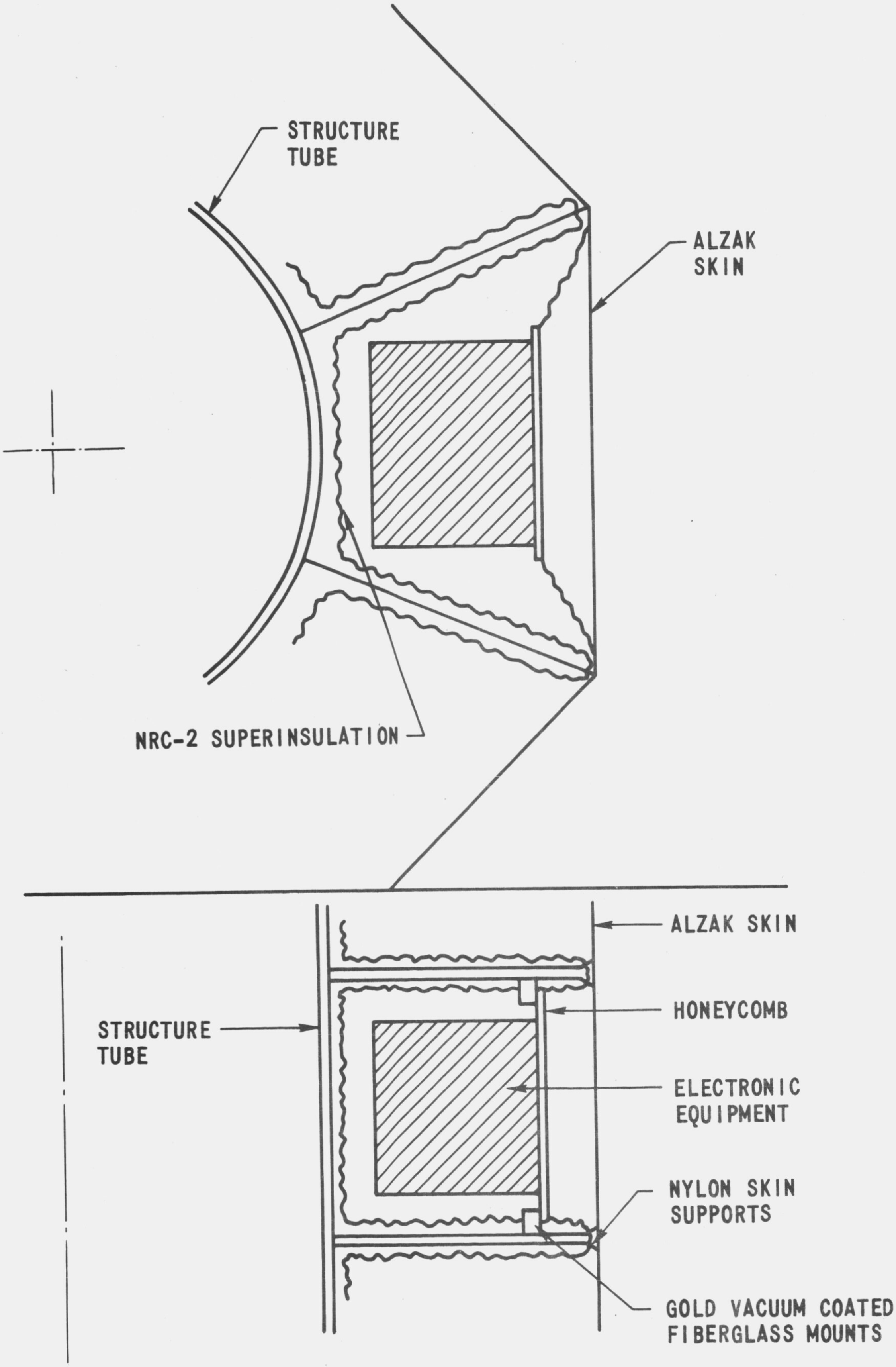

FIGURE 9 - EQUIPMENT BAY DESIGN IN THE OAO (FROM REF. 10)